December 23, 1996

Mr. C. Randy Hutchinson
Vice President, Operations ANO
Entergy Operations, Inc.
1448 S. R. 333
Russellville, AR 72801

SUBJECT: REVIEW OF PRELIMINARY ACCIDENT SEQUENCE PRECURSOR ANALYSIS OF EVENT AT ARKANSAS NUCLEAR ONE - UNIT 2

Dear Mr. Hutchinson:

Enclosed for your information is a copy of the final Accident Sequence Precursor Analysis of the operational event which occurred at Arkansas Nuclear One - Unit 2, reported in Licensee Event Report No. 368/95-001. Oak Ridge National Laboratory (ORNL), our contractor, evaluated your comments on the preliminary analysis of this event, comments from the NRC staff, and comments from our other contractor, Sandia National Laboratories. Enclosure 1 contains the final analysis prepared by the ORNL. Enclosure 2 contains our response to your specific comments. Our review of your comments used the criteria contained in the material which accompanied the preliminary analysis. The results of the final analysis indicate that this event is a precursor for 1995.

Please contact me at (301)415-1367, if you have any questions regarding the enclosures. We recognize and appreciate the effort expended by you and your staff in reviewing and providing comments on the preliminary analysis.

Sincerely,

ORIGINAL SIGNED BY:
Kombiz Salehi, Acting Project Manager
Project Directorate IV-1
Division of Reactor Projects III/IV
Office of Nuclear Reactor Regulation

Docket No. 50-313

Enclosures: 1. Final Accident Sequence Precursor Analysis
2. Responses to your comments

cc w/encls: See next page

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NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 23, 1996

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LER No. 368/95-001

Event Description: Loss of direct current bus could fail both emergency feedwater trains

Date of Event: July 19, 1995

Plant: Arkansas Nuclear One, Unit 2

Event Summary

During a simulator procedure validation exercise, personnel discovered a condition whereby both trains of emergency feedwater (EFW) could be failed by the loss of a single train of direct current (dc) power at Arkansas Nuclear One, Unit 2 (ANO-2). Plant personnel confirmed the validity of the simulator exercise and declared the motor-driven EFW pump inoperable. A 72-hour Technical specification action statement was entered until the bus providing power to the normally open green-powered EFW injection valves could be transferred to an alternate power source that precluded the condition, while a permanent solution could be developed and implemented. A modification to the control relays for the green-powered injection valves in the red EFW train was completed on July 27, 1995 that corrected the condition. The root cause of this condition was the assumption that the green-powered motor-operated EFW injection valves (which replaced the electro-hydraulic injection valves in 1984) would fail "as-is" upon loss of power. Because of a design error during development of the plant modification that implemented the injection valve replacement, a failure of the green train dc bus could cause the green-powered injection valves in series with the two red-powered valves for the motor-driven EFW pump to close enough to restrict EFW flow to the steam generators. The conditional core damage probability (CCDP) estimated for this event is 6.0×10^{-5}. The increase in the core damage probability (CDP), or importance, associated with this event is 1.1×10^{-5}.

Event Description

While validating Abnormal Operating Procedures (AOPs) on the plant simulator, a loss of "green-train" dc power was simulated during power operations. Approximately 3 s into the scenario, the main turbine tripped from loss of dc power to the electrohydraulic control system. The turbine trip resulted in the trip of the main generator output breaker, but, because of the loss of dc control power, the generator field breaker did not trip, and the generator remained tied to alternating current (ac) bus 2A2 via the Unit Auxiliary Transformer. Generator voltage decayed over the next 30 s.

The loss of green-train dc power rendered multiple dependent systems and sub-systems inoperable, including ac buses 2A2 and 2A4, emergency diesel generator (EDG) B, and the A-train turbine-driven EFW pump. In addition, an unexpected interaction rendered the B-train ("red-train") motor-driven EFW pump unavailable.

The discharge of EFW pump B can be routed to either steam generator via lines that each contain two isolation valves. The inboard (closest to the pump) valves are normally closed and are supplied by "red-train" power. The outboard valves are normally open and are supplied by green-train ac power. These valves have a normally energized green-train dc relay, which signals the valves to close on loss of dc control power.

ENCLOSURE 1

review of plant documentation, the LER indicates that sufficient voltage to operate the EFW isolation valves might have existed for only about 10 s after a reactor trip. In this case, the EFW isolation valves would have closed only partially. In that event, some EFW flow—but less than the amount required by technical specifications—might have been maintained.

The ANO-2 Individual Plant Examination (IPE) (Ref. 2) indicates that the expected frequency for the loss of one dc bus is 3.94×10^{-4} per year. The IPE also provides information about the potential impacts of a loss of dc power. Once-through cooling (feed and bleed) requires that either the high-point vent line or one of the low temperature overpressure (LTOP) paths be opened. The loss of green-train dc power would render all pathways unavailable, hence once-through cooling would be unavailable. In addition, a dependency table in the IPE indicates that the following systems are also dependent on green-train dc power: high pressure safety injection (HPSI) train B, shutdown cooling (SDC) train A, and main feedwater (MFW).

Modeling Assumptions

The wiring logic error, which caused the loss of the green-train dc power, apparently existed from the time a plant modification was made in 1984 until 1995, when it was discovered. In this analysis, it was assumed that the plant performance would be similar to that of its simulator. For one operating year [the longest time period analyzed in the Accident Sequence Precursor (ASP) program], both trains of EFW were assumed to be initially inoperable, given a loss of the green-train dc power. The frequency of this initiator, 3.9×10^{-4} per year, was taken from the ANO-2 IPE.

As described above, MFW and once-through cooling are unavailable following a loss of dc power. Core cooling therefore requires successful EFW operation or recovery of EFW if it were to initially fail (this is shown in Figure 1).

The nonrecovery probability of the EFW was calculated by determining:

(1) the nonrecovery probability of operators failing to manually open the EFW discharge valves, and

(b) failure to initiate once-through cooling given EFW is not recovered within 25 min.

The model used to estimate these failure probabilities is the time-reliability correlation given by Dougherty and Fragola in *Human Reliability Analysis* (Ref. 3). These two failure probabilities are then combined to determine the overall probability of operators failing to recover EFW by considering the availability of personnel throughout a 24 h period.

The probability of failing to recover the initially unavailable EFW system was estimated by assuming that the closed EFW discharge valves would be apparent to the operators and that the initial attempt to recover EFW would be by manually opening these valves. Assuming 70 min to core uncovery (Ref. 2, p 3.1-20), ten minutes to implement the emergency operating procedures (EOPs), diagnose the event and determine a recovery strategy, and ten minutes for response, a failure probability of 0.056 is estimated. Because of the

degree of stress expected during such an event, a time-reliability correlation involving "recovery with hesitancy" was used to model the operator response, as described in Ref. 3.

If EFW is not recovered within about 25 min of the start of the transient, the water level in the steam generator (SG) is expected to drop to a value where once-through cooling is required to be initiated (Ref. 2, pp 3.1-19, -20). Because the ability to initiate once-through cooling cannot be met because of the loss of dc power, it is expected that plant personnel will place additional emphasis on recovering EFW. Shortly thereafter, additional resources, if available, are assumed to be used to manually control the turbine-driven EFW pump and its discharge valves in a further attempt to feed water to the SGs. A failure probability of 0.27 is estimated for this action, assuming it occurs 30 min into the event (5 min after the cue for once-through cooling) and requires the 20 min response time specified in Ref. 2.

The failure probabilities for the two recovery actions are:

Recovery	*Failure Probability*
operators fail to manually open the EFW discharge valves	0.056
failure to initiate once-through cooling within time required	0.27

Assuming additional resources are available for initiating once-through cooling except on the back shift (resources are assumed to be available two-thirds of the time) provides an overall probability of failing to recover EFW of:

$$\begin{matrix}\text{probability of}\\ \text{operators failing}\\ \text{to recover EFW}\end{matrix} = [(0.056)(0.27)(2/3)] + [(0.056)(1/3)] = 0.028.$$

These estimates result in the following *increase* in the CDP over a one-year period:

$$3.9\times10^{-4} \left\{\begin{matrix}\text{prob of a loss of}\\ \text{the green dc bus}\end{matrix}\right\} \times \left[1.0 \left\{\begin{matrix}\text{prob of EFW failure}\\ \text{due to wiring error}\end{matrix}\right\} \times 0.028 \left\{\begin{matrix}\text{prob of failure}\\ \text{to recover EFW}\end{matrix}\right\} - 1.1\times10^{-3} \left\{\begin{matrix}\text{nominal failure prob}\\ \text{for EFW train B}\end{matrix}\right\} \right]$$

$$= 1.1\times10^{-5} \left\{\begin{matrix}\text{increase in CDP due}\\ \text{to wiring logic error}\end{matrix}\right\}.$$

Analysis Results

The estimated *increase* in the CDP due to the wiring logic error is 1.1×10^{-5}. The dominant core damage sequence for this event (Sequence number 3 in Fig. 1) involves:

- a postulated loss of the green dc bus,
- the resultant unavailability of EFW, and
- failure to recover EFW.

The *nominal* CDP over a one-year period estimated using the ASP Integrated Reliability and Risk Analysis System (IRRAS) models for ANO-2 is approximately 4.9×10^{-5}. The wiring logic error increased this probability to 6.0×10^{-5}. This value is the CCDP for a one-year period in which the wiring logic error existed.

Acronyms

ac	alternating current
ANO-2	Arkansas Nuclear One, Unit 2
AOP	abnormal operating procedures
ASP	accident sequence precursor
CCDP	conditional core damage probability
CDP	core damage probability
dc	direct current
EDG	emergency diesel generator
EFW	emergency feedwater
EOP	emergency operating procedure
HPSI	high pressure safety injection
IPE	individual plant examination
IRRAS	Integrated Reliability and Risk Analysis System
LER	licensee event report
LTOP	low temperature overpressure
MFW	main feedwater
SDC	shutdown cooling
SG	steam generator

References

1. LER 368/95-001, Rev. 0, "Unanticipated effect of analyzed failure of dc electrical bus upon train of EFW system containing ac motor-driven pump," July 19, 1995.

2. *Arkansas Nuclear One - Unit 2 Individual Plant Examination for Severe Accident Vulnerabilities*, August 1992.

3. Dougherty and Fragola, *Human Reliability Analysis*, Wiley and Sons, New York, 1988.

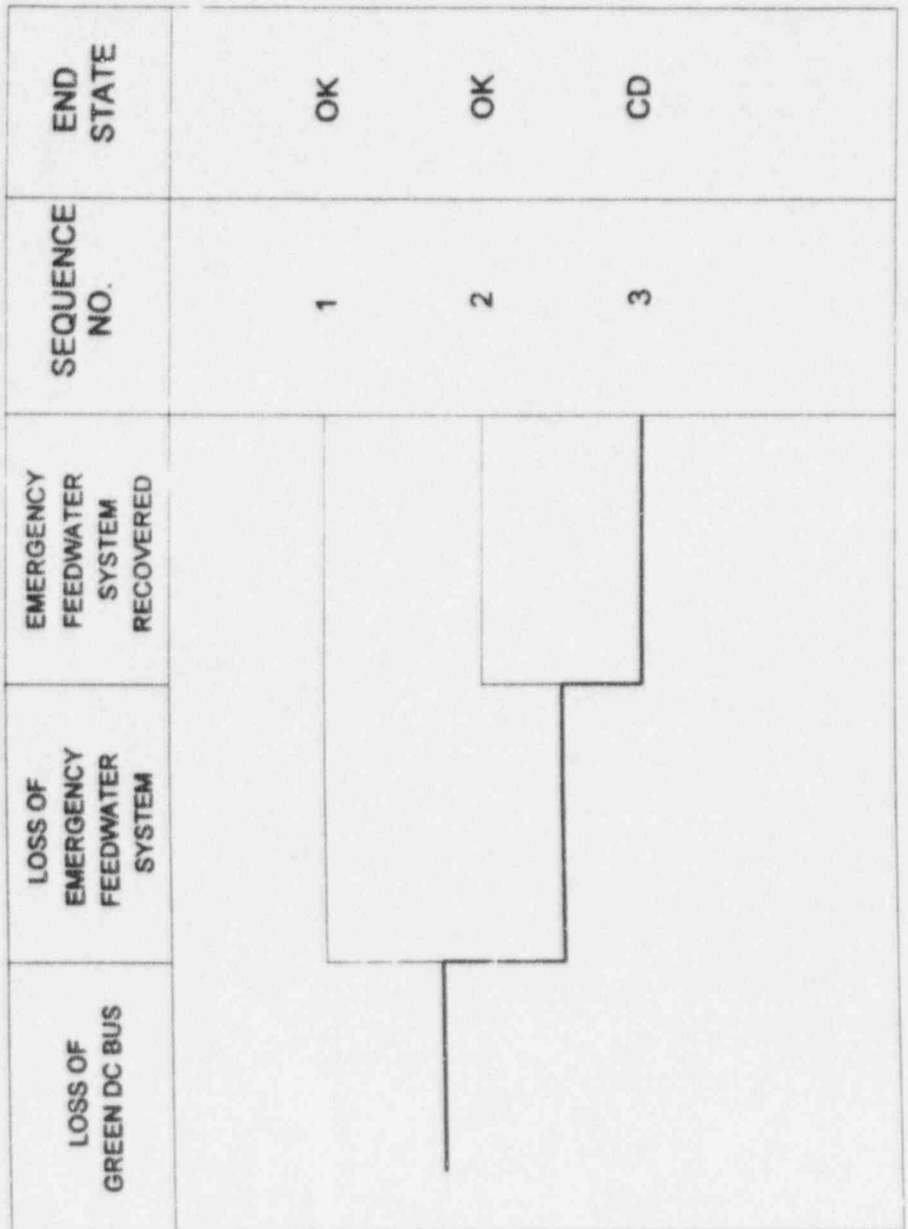

Fig. 1. Dominant core damage sequence for LER 368/95-001.

LER No. 368/95-001

Event Description: Loss of direct current bus could fail both emergency feedwater trains

Date of Event: July 19, 1995

Plant: Arkansas Nuclear One, Unit 2

Licensee Comments

Reference: Letter from D. C. Mims, Director, Nuclear Safety, Entergy Operations, Inc., to U. S. Nuclear Regulatory Commission, transmitting *Arkansas Nuclear One - Unit 2, Docket No. 50-368, License No. NPF-6, Preliminary Accident Sequence Precursor Analysis*, 2CAN099607, September 9, 1996.

Comment 1: (Summary) The **Event Description** is accurate in that it reflects the results of the simulator run. The LER stated that there is no conclusive evidence that the actual plant response to the condition would have resulted in a generator coast down of sufficient duration to allow green train valves to close completely and block all EFW flow. Subsequent investigation has failed to establish a duration of valve motion. A detailed analysis of the voltage decay has not been performed due to the cost. If the EFW performance had been able to exceed the minimum requirements to preclude core uncovery, the event would not have proceeded to core damage via the event sequence originally postulated, and this condition would result in no net change in Core Damage Frequency (CDF). To preclude this from being the case, the valve would have had to travel at its normal speed (which would require its normal voltage) for 16 seconds after the generator tripped.

Response 1: Because a detailed analysis of expected voltage decay was not developed by the licensee, the analysis was based on the assumption that the plant performance would be similar to that of its simulator. This is noted among the modeling assumptions.

Comment 2: While flow blockage due to valve closure is uncertain, potential operator recoveries were examined in order to provide a complete evaluation of the significance of this condition. Two operator recovery actions were identified that would each be successful in restoring

ENCLOSURE 2

EFW flow to the steam generators. These recoveries would have been attempted in parallel to increase the EFW flow, and either would have been adequate if successful. Therefore, in order to have core damage, both recoveries would have to fail.

These recoveries are:

1. Restore power to electrical buses 2A2/2A4 by manually aligning offsite power to 2A2. Reset Main Steam Isolation Signal (MSIS). Open Emergency Feed Water (EFW) discharge valve(s) from the control room.

2. Open EFW discharge valve(s) locally using the handwheel(s).

Only one valve must be opened because heat removal by one steam generator is adequate. The local manipulations for both recoveries are provided with specific lighting that is battery powered and is, therefore, unaffected by the loss of power situation. In addition, adequate power is available through 2A1 such that adequate lighting is available to permit ingress to the local station without impediment. Both recoveries are addressed in procedures 2202.001, "Standard Post Trip Actions," and 2203.037, "Loss of 125V DC," with the specific details of the MSIS reset in procedure 2202.010, "Standard Attachments," Attachment 14, "MSIS Reset." All these actions are a routine part of training received by operators in completing their qualification cards.

Recovery #1 is partially accomplished in the control room and partially in a location that requires entry through a security door. Recovery #2 is accomplished in a location that requires entry into the radiologically controlled access area.

Recovery #1 requires manually opening one breaker and manually closing one breaker outside the control room and electrically opening one valve after resetting MSIS in the control room . . .

The portion of recovery #1 requiring action outside the control room has been determined in the ANO-2 Human Reliability Analysis Work Package (HRAWP) to take 5 minutes and the default value of 4 minutes for the control room portion of the recovery will be conservatively used in series with the portion of the time requirement for actions outside the control room. The time required to accomplish recovery #2 has been determined in the HRAWP to be 10 minutes.

ANO-2 analysis has determined that core uncovery would not begin for at least 40 minutes following steam generator dryout. Values established in ANO-2 analyses indicate that 38 minutes would elapse from the time of reactor trip to the time of steam generator dryout for this scenario with no EFW flow and four Reactor Coolant Pumps (RCPs) running (based on 4.5 MWt into the Reactor Coolant System from each RCP). Therefore, if the EFW valve receives adequate power to completely close, 78 minutes are available to accomplish the

recovery. If the valve does not receive adequate power to close, the additional EFW flow that occurs during the post trip time frame will significantly lengthen the available recovery time even if there is not enough flow to prevent core uncovery without recovery action . . .

Using the Human Recovery Action numerical models developed in the Individual Plant Evaluation (IPE) model with these three input parameters the failure probabilities for recovery are:

Recovery	*Failure Probability*
#1 with 78 min. available time	4.24E-2
#2 with 78 min. available time	3.98E-2
Both #1 and #2 with 78 min. available time	1.69E-3

For these recoveries, a combined failure probability of 1.69E-03 was determined. Since the failure of electrical bus 2D01 was already modeled in the IPE with the exception of this postulated EFW failure, the change in CDF due to the loss of 2D02 initiator (T11) is estimated to be essentially the T11 frequency times the operator failure to recover EFW Train B or 6.66E-07/rx-yr. This is a small increase in the ANO-2 CDF from its estimated value of 3.29E-5/rx-yr, as reported in the ANO-2 IPE/PRA. Note that none of these evaluations, either the original IPE or this re-evaluation, account for the availability of the Station Black Out Diesel generator or the Auxiliary Feed Water train which were installed after the IPE freeze date. The availability of these systems for use in recovering from the T11 initiator could even further reduce the contribution of this new failure mode to CDF.

Considering the additional information presented above that is a result of a more detailed evaluation the section of the NRC letter concerning "Modeling Assumptions" should be reconsidered.

Response 2 The ANO-2 IPE was reviewed to develop an understanding of the recovery approach employed following a loss of dc power. The five most dominant cut sets (as well as eight of the first ten most dominant cut sets, based on the use of plant-specific data) involve the loss of a dc bus, either as the initiating event or as a failure following a reactor trip and loss of an ac bus. Following the loss of a dc bus, main feedwater is lost and EFW is required to feed water to the steam generators (SGs). If EFW is initially unavailable, the water level in the SG will drop to 70 in. in about 25 min. At this water level, once-through cooling is specified by the emergency operating procedures (EOPs) for removing decay heat (IPE pp 3.1-19, -20). Since the loss of either dc bus results in the unavailability of once-through cooling (IPE pp 3.7-2, -3), secondary-side cooling must be recovered if core damage is to be prevented. Core uncovery is estimated to begin 70 min following a transient with initially normal SG water levels, such as a loss of dc power (IPE p 3.1-20).

The IPE recovery analysis assumes different recovery actions, depending on the particular dc bus and subsequent failures included in each cut set. Following the loss of the "green"

dc bus and EFW pump train B (including the EFW ac-powered discharge valves), the IPE addresses the failure of the operators to manually control the turbine-driven EFW pump and discharge valves [basic event P7AMANREC (IPE Table 3.4-1)]. The time required for this action is 20 min (IPE Table 3.4-2). The IPE estimated a failure probability of 0.2 for this action following a loss of feedwater initiating event (55 min to core uncovery). A similar action for the motor-driven EFW pump, that only involves the manual control of the pump discharge valves (basic event P7BMANREC), was estimated to require ten minutes. The failure probability reported for this basic event (recovery #2) is 8.4E-2.

In licensee comment 2, two alternate recovery actions are proposed following the loss of the green dc bus:

recovery #1: recovery of ac power to bus 2A2. This recovery would allow the EFW discharge valves to be opened from the control room. The estimated time to complete this action is 9 min according to licensee comment 2, and 18 min according to the ANO-2 IPE. (The IPE reports this basic event as MANOSPREC, with a 0.13 failure probability for a 70 min available time period).

recovery #2: local manual opening of the EFW discharge valves. The time required for this action is 10 min, which is the same as reported in licensee comment 2 and in the ANO-2 IPE.

These two recovery actions, combined with the potential recovery of EFW through manual control of the turbine-driven EFW pump (based on the IPE, this is the recovery of choice) and the need to recover dc power to provide once-through cooling, as required by the EOPs about 25 min into the event, would compete for available resources. Resources and time expended on one recovery action would not be available for other actions. For this particular event, the licensee's proposed recovery actions are interrelated since they both involve the recovery of the EFW discharge valves and could proceed in parallel, if resources were available, only to the point of valve manipulation. The ANO-2 IPE recovery analysis assumed all ex-control room recovery actions were performed sequentially by a single person (IPE p 3.4-5). While conservative if additional resources are available, the IPE analysis avoided modeling issues associated with the parallel recovery of failed components in a cut set.

Based on information provided by the licensee and the timing information and recovery analysis documented in the IPE, a revised probability of operators failing to recover EFW was calculated. This calculation recognizes the potential for multiple concurrent recovery actions, but does not consider such actions proceeding in a completely independent manner, as assumed in licensee comment 2. The nonrecovery probability of the EFW was calculated by determining:

(a) the nonrecovery probability of operators failing to manually open the EFW discharge valves (recovery #2 given above), and

(b) failure to initiate once-through cooling given EFW is not recovered within 25 min (called recovery #3).

The model used to estimate these failure probabilities is the time-reliability correlation given by Dougherty and Fragola in *Human Reliability Analysis* (Wiley and Sons, New York, 1988). These two failure probabilities are then combined to determine the overall probability of operators failing to recover EFW by considering the availability of personnel throughout a 24 h period.

It was assumed that the EFW discharge valves being closed would be apparent to the operators and that the initial attempt to recover EFW would be by manually opening these valves (recovery #2 in licensee comment 2). Assuming 70 min to core uncovery (as documented in the IPE), ten minutes to implement the EOPs, diagnose the event and determine a recovery strategy, and ten minutes for response, a failure probability of 0.056 is estimated for recovery #2. Because of the degree of stress expected during such an event, a time-reliability correlation involving "recovery with hesitancy" was used to model the operator response (again, see Dougherty and Fragola, *Human Reliability Analysis*, Wiley and Sons, New York, 1988). This probability is consistent with the probability reported in licensee comment 2 (0.0398) and with the ANO-2 IPE (0.084).

If EFW is not recovered within 25 min of the start of the transient, the water level in the SG is expected to drop to a value where once-through cooling is required to be initiated. This requirement, which cannot be met because of the loss of dc power, will provide additional emphasis for EFW recovery. Shortly thereafter, additional resources, if available, are assumed to be used to manually control the turbine-driven EFW pump and its discharge valves in a further attempt to feed water to the SGs (recovery #3). A failure probability of 0.27 is estimated for this action using a time-reliability correlation, assuming the demand occurs 30 min into the event (5 min after the cue for once-through cooling) and requires a 20 min response time as specified in the IPE. This failure probability is consistent with the probability reported in the IPE (0.2).

The failure probabilities for the two recovery actions are:

Recovery	*Failure Probability*
recovery #2: operators fail to manually open the EFW discharge valves	0.056
recovery #3: failure to initiate once-through cooling within time required	0.27

Assuming additional resources are available for recovery #3 except on the back shift (resources are assumed to be available two-thirds of the time) provides an overall probability of failing to recover EFW of:

$$\begin{matrix}\text{probability of} \\ \text{operators failing} \\ \text{to recover EFW}\end{matrix} \quad = \quad [(0.056)(0.27)(2/3)] + [(0.056)(1/3)] = 0.028.$$

These estimates result in the following *increase* in the CDP over a one-year period:

$$3.9\times10^{-4} \begin{Bmatrix}\text{prob of a loss of} \\ \text{the green dc bus}\end{Bmatrix} \times \left[1.0 \begin{Bmatrix}\text{prob of EFW failure} \\ \text{due to wiring error}\end{Bmatrix} \times \right.$$

$$\left. 0.028 \begin{Bmatrix}\text{prob of failure} \\ \text{to recover EFW}\end{Bmatrix} - 1.1\times10^{-3} \begin{Bmatrix}\text{nominal failure prob} \\ \text{for EFW train B}\end{Bmatrix} \right] =$$

$$1.1\times10^{-5} \begin{Bmatrix}\text{increase in CDP due} \\ \text{to wiring logic error}\end{Bmatrix}.$$

This compares to the original estimate of 3.9E-5 as reported in the preliminary ASP analysis.

The revised EFW nonrecovery probability involves substantial uncertainty and may be optimistic. An assumption that the operators would not initially attempt to open the EFW discharge valves and instead attempt to manually control the turbine-driven pump (as utilized in the IPE for green bus dc failures) and that separate action to open the closed EFW discharge valves would be cued at the time that once-through cooling is demanded results in an estimated nonrecovery probability twice as high as developed above (6.6E-2).

The IPE estimates the time required to recover EFW by restoring ac power to bus 2A2 (recovery #1) to be 18 min (licensee comment 2 provides an estimate of 9 min for this action); recovery using this approach would therefore be no more reliable than manually opening the EFW discharge valves, and may involve additional operator burden since ac power would be recovered to a train without dc control power. If resources were diverted to recover dc power at the time that once-through cooling was cued, then recovery of EFW could be further delayed.

As noted by the licensee, the nonsafety auxiliary feedwater pump may provide an alternate method to feed the SGs following a loss of the green dc bus. However, its use would require crew resources that would have to be diverted from the direct recovery of the EFW system. Response time and crew resources are the major factors that influence the probability of failing to recover EFW, and the potential use of a further recovery path within the same time period would be expected to provide little additional benefit. Since the nonsafety AFW pump discharge is routed to the EFW system upstream of the EFW discharge valves, the problems related to these valves would still have to be addressed by the crew. For these reasons, the potential use of the nonsafety AFW pump was not explicitly considered when developing the revised EFW nonrecovery probability.